Perceptual and Motor Skills, 1994, 79, 431-434. © Perceptual and Motor Skills 1994

FOOT AGILITY AND SOCIAL ANXIETY IN OLDER CHILDREN (9-15 YEARS)[1,2]

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Summary.—According to Paul MacLean's phylogenetic model of the brain, the anterior cingulate should be associated with interpersonal emotional bonding. If this assumption is correct, then foot agility (primarily affected by the dorsal medial surface of the cerebrum) should be associated with attenuated bonding and enhanced social anxiety. It would not be associated with finger agility, finger agnosia, or toe agnosia because their integrity involves more distal portions of the cortex. Strong age-dependent and linear increases in agility but not agnosia were shown for the fingers and the feet for normal children (28 girls, 28 boys) between 9 and 15 years of age. As predicted, a correlation of -0.50, not confounded by age or other measures, was noted between foot agility and social anxiety, but was statistically significant for the girls, not for the boys.

Paul MacLean (1990) has argued that the anterior cingulate region is associated with emotional social bonding. In fact, damage to this thalamocingulate system, due to lithium/pilocarpine-induced epileptic seizures, completely abolishes maternal (offspring-bonding) behavior in rats (Peredery, Persinger, Blomme, & Parker, 1992). Panksepp's research (Panksepp, Normansell, Herman, Bishop, & Crepeau, 1988) in conjunction with the results of Vogt and Barbas (1988) suggests that the anterior cingulate region contains copious concentrations of opiate receptors and may explain the common phenomenological correlate of pleasantness and affective affinity during group interactions and the apparent stimulus substitution of human interaction by exogenous opiates that can be inferred from the behavior of morphine and heroin addicts.

Clinically, we have noted that patients who have sustained closed-head injuries exhibit deficits that strongly suggest anterior medial frontal damage. These patients also report an unusual "detachment" or attenuation of bonding with their family and an unusual increase in "social anxiety" subsequent to the accident. The anxiety is sufficient to promote withdrawal and a preference for social isolation whose magnitude is not strongly correlated with psychometric depression. We have suggested that because (a) the anterior cingulate is proximal to the neurons associated with foot agility and (b) the vascular supply of both areas is derived from branches of the Anterior Ce-

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[2]Thanks to the Sudbury Board of Education and the Sudbury District Roman Catholic Separate School Board for their participation in this project.

rebral Artery (Carpenter & Sutin, 1983), differential development of foot agility could be employed as an inference of ontogeny of the anterior cingulate.

Within the adult population (Richards & Persinger, 1992) we have pursued the hypothesis that quantitative measures of foot agility, toe agnosia, finger agility, and finger agnosia can be used as inferences of the functional integrity of the anterior medial surface, paracentral (parietal) lobule, lateral motor strip, and angular gyrus, respectively. If our observations with adults are generalizable, then ontogenetic delays of foot agility should be associated with greater (specifically) social anxiety but not physiological anxiety.

To test this hypothesis a total of 56 (28 girls, 28 boys) children, 9 through 15 years of age (4 boys and 4 girls for each 7-year interval) were selected as subjects. Their participation in the study was contingent upon parental approval and comments by the teacher that each student was within the average range and had not displayed any conspicuous neurodevelopmental problems. On the day of the measurement each child was tested singly. The numbers of finger taps per 10 sec. (Adult Manual Tapper Model 727235; Reitan Neuropsychology Lab, Tucson, Arizona) and numbers of foot taps per 10 sec. (Foot Pedal Model 32738; Lafayette Instruments, connected to an electronic counter) were measured by computing the average of five (alternating) trials for each hand and three (alternating) trials for each foot. Agnosia scores for the fingers and toes (maximum = 20 for each hand or foot) were estimated according to traditional procedures (Reitan & Wolfson, 1985; Richards & Persinger, 1992). The Revised Children's Manifest Anxiety Scale (Reynolds & Richmond, 1985) was then read to each child. It contains four subscales, lie, physiological anxiety, introspective anxiety (worry), and social anxiety. The mean numbers of (agnosia) errors and total taps for the left *and* right hands and for the left *and* right feet were calculated.

The means and standard deviations for the mean total numbers (left and right) of finger taps per 10 sec., foot taps per 10 sec., agnosia errors for the fingers, and agnosia errors for the toes are shown in Table 1 by age interval. Analyses of variance (SPSS; ONEWAY) indicated (all *df*s = 6,49) that only the numbers of finger taps ($F = 7.20$, $p < .001$; $\eta = 0.69$) and foot taps ($F = 7.19$, $p < .001$; $\eta = 0.68$) exhibited any age-dependent changes. Polynomial analyses indicated that the tapping rate for both limbs increased linearly with age and did not deviate significantly from linearity ($F_{1,50}$s = 39.76 and 38.84, $p < .001$). There were no statistically significant differences among the seven age groups for either finger agnosia or toe agnosia. Additional two-way analyses of variance for these four measures as a function of age and sex ($F < 1.00$) did not yield any statistically significant sex differences.

These main effects clearly indicated that, from age 9 years through age 15 years (the criterion for "adulthood" for many neuropsychological tests), there are no conspicuous alterations in discriminability for the toes or fingers

TABLE 1
MEANS AND STANDARD DEVIATIONS FOR MOTOR AGILITY OF HAND AND FOOT AND TOTAL NUMBERS OF ERRORS FOR AGNOSIA FOR FINGERS AND TOES OF CHILDREN 9 THROUGH 15 YEARS OLD (n = 8/AGE GROUP)

Age, yr.	Finger Tapping		Foot Tapping		Finger Agnosia		Toe Agnosia	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
9	38.3	2.9	31.4	8.3	0.5	0.9	5.9	1.3
10	42.9	5.3	33.1	4.9	1.1	1.1	5.6	1.7
11	44.3	4.7	34.7	5.6	0.4	0.4	4.9	1.6
12	45.7	3.1	37.2	4.3	1.1	1.8	3.5	2.2
13	45.7	4.3	43.4	4.8	0.7	0.8	4.5	2.1
14	49.6	4.4	43.4	5.2	0.5	1.0	5.1	2.3
15	50.0	4.5	43.1	5.4	0.5	1.0	3.8	2.3
Σ	45.4	5.4	38.3	7.2	0.7	1.0	4.7	1.9

while motor agility continues to improve. These results suggest that the development of the lateral (finger location) and paracentral (toe location) parietal lobes have reached asymptote (at least for these tasks) by age 9 years while indices of lateral and paracentral prefrontal function continue to develop. Whereas the mean difference between finger agility for 9-year-olds and 15-year-olds is equivalent to at least 3 standard deviations, the analogous difference for foot agility is equivalent to about 1.5 to 2.0 standard deviations.

To detect recondite differential development in the three domains of measurements for the hands and feet, three-way analyses of variance with one level repeated (hands, feet) and two nonrepeated (sex, age) were completed for the agility and agnosia tasks separately (SPSS: MANOVA). In addition to the age differences that had emerged for the motor tasks, there were conspicuous differences between limbs for the motor tasks ($F = 67.42$) and agnosia ($F = 331.10$; see Table 1 for means) tasks. There was only one statistically significant interaction for agnosia errors ($F_{6,44} = 2.64$, $p < .05$) between age and fingers/toes.

The general absence of major differential ontogenetic changes in the proficiency for the fingers and toes was verified when the mean values for feet/toes were subtracted from the mean values for the hands/fingers for each of the three tasks for each subject. One-way analyses of variance indicated no statistically significant differences ($F < 1.00$) between ages for these mean differences for the motor tasks; the M and SD were 7.1 and 6.6, respectively. The weak but statistically significant ($F_{6,49} = 2.72$, $p < .05$) age effect for the absolute differences in toe-finger agnosia errors was due primarily to relatively less discrepancy for the 12-yr.-olds (2.4 and 1.0) relative to the 9-yr.-olds (5.4 and 0.9) only; the M and SD for all age groups were 4.1 and 1.8.

The hypothesis that relatively delayed development within the anterior medial surface would be more associated with difficulties in social bonding as defined by enhanced social anxiety was supported for the girls ($n = 28$)

but not for the boys. The means and standard deviations for the total standardized score, the four subscales of anxiety, and the lie scale did show statistically significant ($p < .05$) gender differences; these values were for total anxiety 48 3 and 8.8, for the physiological anxiety score 9.3 and 2.7, for the rumination score 9.1 and 2.4, for the social anxiety score 9.1 and 2.5, and for the lie score 9.8 and 2.9. Girls showing less age-appropriate foot-tapping agility exhibited more specific social anxiety ($rho = -0.51$, $p < .01$) but neither physiological nor introspective anxiety ($rhos < 0.30$).

Partial correlation analyses (age variance held constant) showed that elevated social anxiety (-0.53) and introspective worrying (-0.55) but not physiological anxiety (-0.30) or the lie scale (0.07) were associated with mean foot agility; none of the anxiety scores were significantly correlated with finger agility or with the agnosia indicators. That the effect was specific to foot agility and not a general artifact of delayed limb development was indicated by the maintenance of the same magnitude and direction of these correlation coefficients when the variance associated with toe agnosia was held constant. When the variance associated with mean finger agility was removed, the association between foot agility and social anxiety ($r = -0.42$) and worry ($r = -0.46$) remained statistically significant. Stated alternatively, the correlation between the mean discrepancy in agility for the hands and feet was positively associated with social anxiety ($r = 0.52$).

The results of this study support the hypothesis that relatively poorer foot agility should be associated with delayed maturation of the anterior medial surface of the cerebrum. We have assumed, although there are clearly other possibilities, that delayed capacity for age-appropriate bonding should be associated with enhanced social anxiety. A more mundane explanation is that girls who exhibit poorer foot agility than finger agility may simply be more clumsy and hence less proficient on tasks, e.g., dancing, ballet, that are often important for peer-group affiliation; were this correct, anxiety would be secondary to the consequences of the clumsiness and lowered self-esteem.

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Accepted June 21, 1994.